

United States Air Force Research Laboratory



TEAM COMMUNICATION AND PERFORMANCE DURING SUSTAINED COMMAND AND CONTROL OPERATIONS: PRELIMINARY RESULTS

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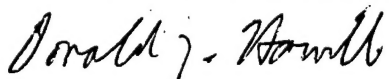
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14. ABSTRACT This report describes the approach and initial results of an investigation of individual and team Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) communication and performance in complex time-critical targeting sustained operations (SUSOPS) scenarios. There have been few experimental studies on the effects of fatigue on complex decision making. Therefore, we have initiated a program of research that extends this effort by (a) utilization of a complex command and control simulation based on demanding and time-critical USAF operational tasks, and (b) utilization of operational USAF military personnel as research participants. We describe our initial baseline study, and preliminary findings regarding effects on communication processes. As expected in overnight sessions, the subjects significantly changed their communications that they were fatigued. Their fatigue was also potentially reflected in the subjects significantly changing two other types of communications: 1) requesting information on assets; and 2) strategy (information regarding the movement of assets or the sequencing of actions among team members). Future studies will extend this baseline investigation and assess potential countermeasures for acute and chronic fatigue effects in sustained operations.					
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PREFACE

This report covers the project period of October 2002 to August 2003. The work was performed under Job Order Number 7757P904.

The project manager was 1st Lt Christopher Barnes (AFRL/HEPM), Biodynamics and Protection Division, Air Force Research Laboratory.

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SUMMARY

This report describes the approach and initial results of a systematic investigation of individual and team Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) communication and performance in complex time-critical targeting sustained operations (SUSOPS) scenarios. To date, there have been few experimental studies on the effects of fatigue on complex, time-critical decision making. A preliminary study, based on a team threat assessment task, using college students as research participants, reported significant effects on team decision outcomes, coordination, and communication processes (Mahan, 1992, 1994; Mahan, Elliott, Dunwoody, & Marino, 1998). As a result, we have initiated a program of research that extends this effort by (a) utilization of a complex command and control simulation based on demanding and time-critical USAF operational tasks, and (b) utilization of operational USAF military personnel as research participants. In this report, we describe our initial baseline study, and preliminary findings regarding effects on communication processes. As expected in overnight sessions, the subjects significantly changed their communications as fatigue set in. Their fatigue was also reflected in the subjects significantly changing two other types of communications: 1) requests for information on assets; and 2) strategy regarding information on the movement of assets or the sequencing of actions among team members. Future studies will extend this baseline investigation and assess potential countermeasures for acute and chronic fatigue effects in sustained operations.

INTRODUCTION

United States Air Force (USAF) command and control (C2) warfighters face increasingly complex environments that represent the essence of naturalistic decision making--multiple demands for enhanced vigilance, rapid situation assessment, and coordinated adaptive response (Cohen, 1993; Klein, 1993; Mitchell & Beach, 1990; Orasanu & Salas, 1991; Orasanu & Connolly, 1993; Rasmussen, 1993). In tactical C2 situations, the focus is on dynamic battle management and time-critical targeting. Information updates may be from air or from ground sources. Coordination demand is high--reconnaissance and resource allocation depend upon close coordination between ground and air forces, in a distributed network of systems. Situations requiring close coordination and adaptive planning are increasingly prevalent and challenging.

Clearly, challenges within these battle scenarios impact air and ground superiority. The development of advanced technology is focused to provide and represent time-critical information during mission execution. These capabilities are needed to facilitate situational awareness and coordinated response in conditions of information complexity and time pressure. However, advanced technology only supports, the role of the war fighters. It can be argued that advances in technology increase the role and demands of the human decision maker.

Decisions and Responses of C2 Operators

As advanced technology affords paradigm shifts in information technology, it impacts C2 decision makers or troops on the ground, who must make tactical decisions under duress, often for long periods of time. Despite any particular advanced technology, individual performance will still vary, depending on the competence of each individual with regard to situational demands. To lessen this impact, we must determine how to enhance the processes by which war fighters recognize, interpret and respond effectively in these situations (Elliott, Covert, & Miller, 2003).

Current military scenarios blend operators and technology in a complex, dynamic, and interdependent system. Complex coordination must include adaptive problem solving by the human components. Prime examples include dynamic re-allocation of assets, for purposes such as retargeting and search-and-rescue. In these situations, effective response inevitably involves interaction with others: typically, information and/or resources must be distributed effectively and task events must be sequenced.

Sustained Operations and Fatigue

Sustained operations are integral to command and control--combat missions require vigilance over time and adaptive performance under stress. During the early stages of actual scenarios, members of the command center are often up for several days with little if any time for recuperative sleep. Over time, chronic fatigue will affect everyone, and the likelihood of error will increase (Hursh, 1998). This is particularly relevant to C2 situations, which require constant monitoring, even when events are still.

There is extensive documentation on the negative impact of acute and/or chronic sleep loss. In a review of findings, Bonnett (2000) reports an array of negative effects. These effects include mood changes, disorientation, irritability, perceptual distortions, hallucinations, difficulty in concentration, and/or paranoid thinking, depending on the extent of sleep loss. Negative

effects have also been demonstrated on a range of cognitive tests, such as monitoring tasks, speed/accuracy tests, short-term memory, logical reasoning, and mental subtraction/addition. Physiological effects are reflected in a variety of physiological tests, such as EEG, nystagmus, hand tremor, slurring of speech, sluggish corneal reflexes, hyperactive gag reflex, and increased sensitivity to pain.

Research Needs on Fatigue, Team Communication, and Performance

While extensive data are available on effects of sleep loss on physiological, attitudinal, and cognitive function (Kryger, Roth, & Demnet, 2000), very few studies reported data regarding sleep loss effects on particular aspects of information processing in complex team performance or decision making tasks. A few preliminary studies provide some introductory results (Mahan, 1992, 1994; Mahan, Elliott, & Dunwoody, 1998; Coover, et al., 2001; Hollenbeck, Ilgen, Tuttle, & Sego, 1995). To continue this stream of research, the Warfighter Fatigue Countermeasures R&D program at Brooks City-Base, TX has initiated a program of research that extends this effort by (a) utilization of a complex command and control simulation based on demanding and time-critical USAF operational tasks, and (b) utilization of operational USAF military personnel as research participants. The focus will be on effects of sleep loss on information processing, communication, coordination, and decision making in team based sustained C4ISR simulation-based task environments. In this paper we shall describe preliminary baseline study design and results, with a focus on issues related to elicitation and assessment of team communications.

C4ISR team scenarios were chosen for USAF operational relevance and the need to understand dynamics of communication, shared awareness, coordinated action, and adaptive response to time-critical situations. C4ISR scenarios were crafted such that mission planning, team coordination and dynamic planning are critical to team success. Scenarios were carefully constructed to ensure equivalence in task demand and difficulty (Elliott, Coover, Barnes, & Miller, 2003). We predicted that fatigue will have a detrimental effect on performance, and particularly on indicators of problem identification, communication, task sequencing, and asset redistribution. In this report, we focus on measures of communication as indicators of information exchange and task sequencing, and describe initial relationships of measures of team process and performance.

METHOD

Participants

Research participants were drawn from a pool of USAF officers awaiting Air Battle Management Training at Tyndall AFB, FL. A total of ten 3-person teams participated in this study. Although all the participants had already attended the Aerospace Basics Course, it provided them with little training or knowledge useful for the current study. The participants were assigned to the 325th Air Control Squadron, Airborne Battle Managers Undergraduate, Ground (325 ACS-ABM-AUG).

Of the first five, three-person teams, two were composed of three males, two were composed of two males and one female, one was composed of one male and two females. Due to the large amount of time involved in transcribing and coding communications, the next five three person teams are not included in this paper's results and discussion.

Training

Each team participated in a 40-hour, one week training session. The training included one hour of administrative processing, nine hours of training on the Automated Neuropsychological Assessment Metrics (ANAM) cognitive test battery (Reeves, Winter, Kane, Elsmore, & Bleiberg, 2001) to reach specified performance levels, and training on C4ISR assets, capabilities, and tactics, along with Agent Enabled Decision Group Environment (AEDGETM) interface functions (30 hours). The subjects were trained in three distinct C2 functional roles: ISR (Intelligence, Surveillance, and Reconnaissance), SWEEP, and STRIKE. The ISR role owns assets related to ISR functions, such as unmanned aerial vehicles (UAV). The STRIKE role owns assets such as air-to-ground bombers and airborne jammers, while the SWEEP role owns assets such as air-to-air fighter aircraft. During this time, the various ergonomic features of the chairs and workstations were explained and demonstrated to the participants. Participants learned principles of these ergonomics and how they can be adjusted to aid with fatigue effects.

Experimental Manipulation

The experimental session began at 6pm on the last day of training (always a Friday) and ended at 11am the following morning. With one subject in the role of STRIKE, one as SWEEP, and one as ISR, they participated as three-person teams, every other hour, in eight 40-minute team-based C4ISR decision making scenarios, with 20 additional minutes during each session for debriefing, data collection, and mission planning for the next session. Their roles as STRIKE, SWEEP, or ISR did not change during the experimental sessions. Every other hour, between each scenario session, they performed on the ANAM cognitive test battery that assesses reaction time, working memory, simple mathematical processing, and multitasking (Reeves, et al., 2001). After each cognitive battery session, physiological data (e.g., temperature, actigraphy) was taken, as well as self-reports on mood-state and sleepiness. All email and audio communications were digitally captured for transcription. This resulted in extensive cognitive performance and simulation-based process and performance data.

Elicitation of Performance

Criterion measures of simulation-based performance were generated from a PC-based synthetic team task environment developed for investigations of C4ISR team performance. The Airborne Warning and Control System (AWACS) AEDGETM (Agent-Enabled Decision Group Environment) is constructed as a federation of intelligent agent-based functions, that enable PC-based scenario construction and emulation of C4ISR information and cognitive task demands (Hicks, Stoyen, Zhu, 2001; Petrov & Stoyen, 2000). These PC-based scenarios operate much like a networked videogame. However, the scenarios are scaled to capture realistic operator decision making and performance demands (Elliott, Dalrymple, Schiflett, & Miller, in press; Schiflett & Elliott, 2000). Functional and cognitive fidelity was based on cognitive task analyses (Chaiken, Elliott, Dalrymple, & Schiflett, 2001).

C4ISR functions in AEDGETM scenarios were typified by a strong demand for communication, coordinated action, and adaptive response to time-critical situations. Complexity in these scenarios was enhanced by the addition of an AEDGETM software agent to

play the role of a fourth team member, whose responsibility was to maintain high value assets such as tankers and airborne reconnaissance platforms. The goals in scenario development were to (a) capture operational relevance to C4ISR (content fidelity), (b) identify and assess aspects of individual and team performance (construct fidelity), (c) develop scenarios that are equivalent in difficulty (cognitive fidelity), and (d) not have exact replicas of each other. If participants perform the same scenario over and over, then effects of fatigue will be confounded with effects of practice and recognition-based performance. Scenarios had to be demanding, operationally relevant, equivalent in difficulty, and yet be distinct from each other (Elliott, Coovert, Barnes, et al., 2003).

The C4ISR functions reflect those of current and future command centers that coordinate across diverse functional, geographic, military, national, and political characteristics. General principles of mission goals and tactics were identified and reflected in the AEDGETM scenarios to ensure content fidelity. At the same time, scenarios must reflect research goals—performance constructs must be identified, elicited, and assessed in order to achieve construct fidelity of the scenarios. We constructed scenarios with task demands that will ensure elicitation and enable assessment of team communication, coordinating activities, problem recognition and adaptive planning on the part of the participants.

Descriptions of Scenarios

Participants performed in eight 40-minute mission scenarios. While geographic context (Taiwan and Cyprus) and particular hostile targets varied among the scenarios (hostile theatre ballistic missiles, hostile navy assets, hostile scud missile launchers), great effort was applied to ensure equivalent task demands. The primary mission was always the same: Find and Destroy hostile targets. The same number of targets (20) was presented in each scenario. Ten were presented within the first five minutes of the scenario, while the remaining 10 were “popup” targets that appeared systematically throughout the scenario. In all scenarios, half the targets were always decoys, such that dynamic planning and retargeting was necessary. All targets were placed about the same distance from the friendly weapon assets. All targets appeared in similar task tempos. All friendly assets were equivalent in each scenario. In each scenario, all friendly roles started with the same type and number of assets, and were presented with additional assets equivalent in type and timing across the scenarios. Thus, for every five-minute increment in each scenario, participants owned the same number of assets and faced the same number of hostile targets—except any losses of targets and assets resulting from their own performance. Throughout the scenario, the subjects monitored the fuel and armament states of their controlled assets and performed aerial refueling when necessary. Friendly assets were systematically presented with regard to fuel states: some were presented that necessitated immediate refueling, while others would require refueled during the scenario to ensure efficient processing of task demands.

Measures

Mission Outcomes

Raw measures of mission outcome and team process were captured and time-stamped by the simulation. These included descriptions and counts of events and actions, which then formed the basis for various assessments of performance. For example, mission outcome scores were

represented by the type, number, and relative value of lost assets by "friendly" and "hostile" roles. Friendly assets included air bases, cities, surface-to-air missile launchers, uninhabited aerial vehicles, tanker aircraft, high-value reconnaissance aircraft, fighter aircraft, and bomber aircraft. Additionally, the measures were broken down by types of friendly versus hostile assets. Examples of this breakdown include hostile MIG31s killed by friendly fighters, hostile MIG31s killed by friendly bombers, hostile MIG23s killed by friendly fighters, hostile MIG23s killed by friendly bombers, hostile MIG21s killed by friendly fighters, and hostile MIG21s killed by friendly bombers. A sample of the data collected, 'total friendly assets killed by hostile action' is reported in the current paper. Each asset was given a relative score value, generated by our weapons director expert, and validated by other experienced weapons directors. The loss of any friendly asset detracts from the score of the friendly team, and adds to the score of the enemy. In turn, hostile assets are similar. 'Total hostile assets killed by friendly action' is also reported in the current paper. The loss of hostile assets adds to the score of the friendly team, and detracts from the score of the hostile. For these research participants, the overall mission outcome score was based on the point value obtained after subtracting all friendly "losses" from the total hostile "losses."

Audio Capture of Communications

Digitally recorded communications were another critical source of assessment. Communications were initially coded for indications of teamwork, such as sharing of information or assets, sequencing actions, acknowledgements, requests for repeats, task-related encouragement, expressions of fatigue, and social comments (positive and negative) (Harville, Elliott, Barnes, & Miller, 2003).

Analysis of Communications (Computer-mediated and Verbal)

All audio was digitally captured, and is in the process of being coded to ascertain the degree to which the team (a) shared information and (b) discussed sequencing their activities, for each phase of performance. We are coding the number of times each team member: 1) requested information about a target, asset, or unknown type of entity; 2) provided information about a target, asset, or unknown type of entity; 3) engaged in strategy communications; 4) requested acknowledgements; 5) provided acknowledgements; 6) requested repeats, 7) provided repeats; 8) communicated fatigue; 9) communicated encouragement; 10) communicated on the time remaining in the scenario; and 11) had other communications. Due to their hypothesized importance, as well as higher agreement by independent coders, this paper focuses on requesting information about a target or asset, providing information about a target or asset, strategy, encouragement, and fatigue. All of these seven categories of communication are hypothesized to change as the subjects become fatigued.

The first two categories of communication, requesting and providing various types of information, dealt with information activities (non-sequencing communications, such as queries, alerts, reminders, friendly and hostile conditions, etc.), while the third (strategy) involved coordinating activities (sequencing tasks, sharing assets, requests for transfers of assets between the subjects, orders to transfer, coordination of transfers, sending transfers, receiving transfers, denying transfers, aborting transfers, etc). We correlated quantitative indices of events, such as the number of times a handoff request or "push" (when a team member offers an asset to another) was accepted or denied (from whom to whom). Other quantitative indices included the number of times team members scoped (i.e., zoomed) in or out (related to situation awareness), the number of times they opened information windows on assets, the number of times a decoy was

correctly identified, assets refueled and/or rearmed, penetration of friendly area by enemy, and all outcome measures (targets destroyed by whom, etc).

We predicted these indices of coordinating behavior, anticipatory behavior, and situational awareness-related behavior would change with fatigue. People would tunnel in, not notice the predicaments of others, not care (share resources), and not realize when new bandits arise, or when additional friendly resources were available. They were also expected to fail in sequencing activities, such that decoys were not identified, vulnerable friendly assets were lost, and hostile targets were not executed. They were also expected to lose friendly assets due to fuel outs.

RESULTS

For background information on trends, the means and standard deviations for some kills in each scenario, are presented in Table 1. These results are broken down by mean number of 'friendlies killed by hostiles,' mean number of 'Hostiles Killed By Friendlies,' as well as the difference of these two means (hostiles killed minus friendlies killed). The general trends across scenarios were as expected. The minimums for these three means were all in the sixth scenario, which always started at 4:30am. However, the mean 'Friendlies Killed By Hostiles' was expected to be at the maximum, not at the minimum, for scenario 6. 'Mean Friendlies Killed By Hostiles' peaked at scenario 2 with a value of 8.00, and with a value of 7.80 almost repeated that peak at scenario 5. As expected, 'Mean Hostiles Killed By Friendlies,' with a value of 26.40, was at the minimum for scenario 6. Also as expected, the difference between the two means (hostiles killed minus friendlies killed) was at the minimum for scenario 6.

Scenario Number	Mean Total Friendly Assets Killed by Hostile Action	Standard Deviation Friendlies Killed by Hostiles	Mean Total Hostile Assets Killed by Friendly action	Standard Deviation Hostiles Killed by Friendlies	Mean (Hostiles Killed – Friendlies Killed)	Standard Deviation (Hostiles Killed – Friendlies Killed)
1	5.000	5.244	43.600	7.603	38.600	12.621
2	8.000	2.828	37.400	2.510	29.400	5.079
3	0.800	1.304	28.600	2.881	27.800	3.421
4	1.000	1.732	47.800	5.215	46.800	6.058
5	7.800	3.347	35.800	4.438	28.000	7.071
6	0.400	0.894	26.400	5.814	26.000	5.831
7	4.800	6.380	45.400	9.762	40.600	15.837
8	3.000	4.123	43.800	8.871	40.800	12.498

Table 1. Sample kills data.

Coding of communications resulted in acceptable reliability (over 96% agreement). Scenario 1 can be considered to be the baseline, while as reported in Table 1, the three minimum kills all occurred in scenario 6. For scenarios 1 and 6, the total communication counts (ISR +

SWEEP + STRIKE) by category are presented in Table 2. T-tests (2-tailed) comparing scenario 1 means to the scenario 6 means are also reported. Due to a small sample size and to reduce false negative errors, a significance level of 0.10 was used. There were significant scenario 1 to scenario 6 differences for three of the seven variables: request information asset, strategy, fatigue. While not statistically significant changes, two other variables changed by more than 45%. 'Provide information' asset changed by 47.5%, from 35.4 to 18.6. 'Encouragement' changed by 64.0%, from a value of 10.0 to 3.6. With a larger sample size or a lower standard deviation these changes would be significant.

	Provide Information		Request Information				
SUM (Team, Scenario)	Target	Asset	Target	Asset	Strategy	Encouragement	Fatigue
SUM (1, 1)	7	28	43	69	162	10	0
SUM (2, 1)	36	67	5	32	86	11	1
SUM (3, 1)	27	35	0	14	62	5	2
SUM (4, 1)	25	27	3	7	38	24	0
SUM (5, 1)	24	20	4	9	54	0	1
AVERAGE, SD	23.80, 10.52	35.40, 18.45	11.00, 17.99	26.20, 25.88	80.40, 48.79	10.00, 8.97	0.80, 0.84
SUM (1, 6)	18	20	44	52	72	10	21
SUM (2, 6)	26	10	6	5	28	4	26
SUM (3, 6)	24	12	1	4	17	1	13
SUM (4, 6)	22	14	3	0	6	2	25
SUM (5, 6)	37	37	9	9	41	1	15
AVERAGE, SD	25.40, 7.13	18.60, 10.95	12.60, 17.81	14.00, 21.48	32.80, 25.47	3.60, 3.78	20.00, 5.83
p (2-tailed t-test)	0.737	0.235	0.140	0.057	0.021	0.198	0.003

Note: SUM = ISR + SWEEP + STRIKE for a given communication type, team, and scenario

Table 2. Communication counts and t-tests for scenarios 1 and 6.

DISCUSSION

The fact that fatigue affects performance is without doubt (Elliott, et al., 2002). Research has afforded much insight with regard to the impact (and measurement) of fatigue on various

aspects of human performance. Advancements in theory and measurement have led to development of quantitative models for prediction of fatigue effects, and to fatigue countermeasures. The predictive model has been optimized to predict changes in cognitive performance in addition to alertness and incorporates features such as: a multi-oscillator circadian process, a circadian sleep propensity process, a sleep fragmentation process, and a circadian phase adjusting feature for time zone changes (Eddy & Hursh, 2000; Hursh, 1998).

This paper only analyzed a portion of the data collected in this investigation. Data for all 10 weeks and from all sources will ultimately be analyzed using a multi-level hierarchical modeling approach. This approach enables consideration of performance data of individuals, clustered in teams, to ascertain relationships and trends over time (Kreft, & De Leeuw, 2000). We will focus on how individual performance affects team performance, and how both are affected by fatigue.

The results disproved the null hypothesis for three of the seven variables with regard to communications (request information asset, strategy, and fatigue). These results are consistent with indications that as teams become fatigued, they do not communicate as often. While not statistically significant changes, two other variables changed by more than 40%. 'Provide information asset' changed (decreased) by 47.5%, while 'encouragement' changed (decreased) by 64.0%. With a larger sample size or a lower standard deviation these changes would be significant.

Further stages of this program of research are currently in the planning process. The next stage will increase the sample size, providing more statistical power. It is encouraging that significant results have already been found at this early stage, and it is expected that future stages will further clarify the effects of fatigue on team performance. It is already clear at this point that fatigue has an effect on team performance. Future steps will include better quantification of the effects and eventual creation of strategies to minimize and counter such effects.

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